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Communications Division

REPORT
ERL-0519-RE

METEOR BURST COMMUNICATIONS STUDY.

by

John A. Hackworth

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SUMMARY

This report documents the results of a study into the use of a Meteor Burst Communication System over the southern part of the Australian continent. Also included is a description of the equipment used in the study and some suggestions for further work.

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ABBREVIATIONS

ADO	Australian Defence Organisation
AGC	Automatic Gain Control
ASCII	American Standard Code for Information Interchange
AWA	Amalgamated Wireless Australia
DSTO	Defence Science and Technology Organisation
EMI	Electromagnetic Interference
EPROM	Electrically Programmable Read Only Memory
ERL	Electronics Research Laboratory
HP9000	Hewlett Packard proprietary equipment
IERP	Isotropic Effective Radiated Power
IF	Intermediate Frequency
IPS	Ionospheric Prediction Service
MBC	Meteor Burst Communications
NF	Noise Figure
RAM	Random Access Memory
RF	Radio Frequency
UTC	Universal Coordinated Time

1 INTRODUCTION

Tiny particles, the size of grains of sand, are constantly being swept up by the earth on its orbit around the sun. Travelling at speeds of up to 70 km/s, these particles disintegrate in the upper atmosphere, leaving a thin trail of ionised gas which lasts for about a second, at a height of between 80 and 120 km above the earth. Radio signals (up to VHF) are reflected back to earth from these trails, but are so weak as to generally go unnoticed. Each favourably orientated trail specularly reflects the incident radio rays, directing a narrow beam of signal back to earth over a confined area. A sensitive receiver can detect these reflections as brief bursts of signal separated randomly by a few seconds.

Experimental communications systems utilising this phenomenon and designated Meteor Burst Communications (MBC) systems have been the subject of spasmodic research, mainly in the northern hemisphere, for the past 40 years or so. [1]. While some countries are already using MBC systems to solve particular communication problems, there has been little interest shown in Australia to date.

MBC systems, in a similar way to some forms of currently emerging communications technology, rely on compressing the information to be transferred into small packets and then transmitting it as a series of short bursts. The transmitted energy is reflected from a suitable meteor trail back to the receiving station where it is reassembled into useful information. The maximum range of such communication is limited by the height of the meteor trails and by the curvature of the earth and in practice has been found to be approximately 2000 km [2].

This report describes an experimental MBC system developed at the Electronics Research Laboratory (ERL) specifically to study the phenomenon over the southern part of Australia. Whilst the report gives a brief explanation of the equipment used, it is primarily concerned with the results of the trials conducted during the study program. Also included are some suggestions for further work, particularly in regard to computer modelling techniques.

2 MONITORING OF METEOR TRAIL REFLECTIONS

While awaiting delivery of a purpose-built transmitter to complete the ERL Meteor Burst Communications system, the opportunity was taken to exercise the receiver system by monitoring the meteor trail reflections of the video carriers of Australian television stations operating on channel 0 (46 MHz).

The only high power stations operating at the time were TVQ in Brisbane, 1580 km from the receiver, at a bearing of 63° true and ABMN Channel 0, near Gundagai, 845 km from the receiver site at a bearing of 93° true. The horizontally polarised radiation of both of these stations was approximately 20 kW, effective isotropic average carrier power. The actual carrier frequencies of the stations were 46.172 and 46.240 MHz respectively, which enabled

them to be readily distinguished. The receiving station at ERL was located at latitude 34° 44', longitude 138°, 38'. A functional diagram of the receiving station equipment used is shown in Figure 2. The receiving antenna was a rotatable horizontal halfwave dipole mounted on an eight metre mast. The dipole was centre-fed by two separate coaxial cables, one connected to each quarterwave arm. A vertical halfwave counterpoise element was connected to the cable shields at its centre. The two coaxial cables fed two identical receivers, the local oscillators of which were locked together to facilitate measurement of the phase difference between the two IF outputs. This phase angle was calibrated to indicate the direction of the meteor burst signals arriving at the antenna. The receiver's automatic gain control (AGC) voltage was also calibrated to register input signal levels. The ambient noise level was usually between -130 and -120 dBm in the IF bandwidth of 4.8 kHz. Local noise from nearby high tension power lines was the cause of most of the noise at the higher levels. The data logger, which was an HP9000 instrument controller with an analogue interface, recorded all bursts of signal above a fixed threshold (usually -110 dBm), noting the peak amplitude, the duration of the burst and the angle of arrival.

The reception of signals from the Brisbane station TVQ0, during the summer of 1987, is shown in Figure 1 below. It is shown as a pattern of dots where each dot represents the occurrence of a burst at the time shown on the horizontal axis and at the angle of arrival shown by the vertical axis. The horizontal axis is local time (UTC plus $9\frac{1}{2}$ hours). Recording was started during the Australian summer when sporadic E propagation (Es) often occurs over this path. Clearly seen is a concentration of the angles of arrival in two directions (hotspots) to the north and south of the direct path, separated by about 27°. Also evident is a diurnal variation in the intensity of the hotspots. In particular the southern one fades during the late afternoon.[2] The gaps in the record indicate when the TV station closed down overnight. The average detected burst rate of 46 per hour and duty cycle of 0.4% were calculated for the 20 hour period of January 27th 1987, a day free of sporadic E.

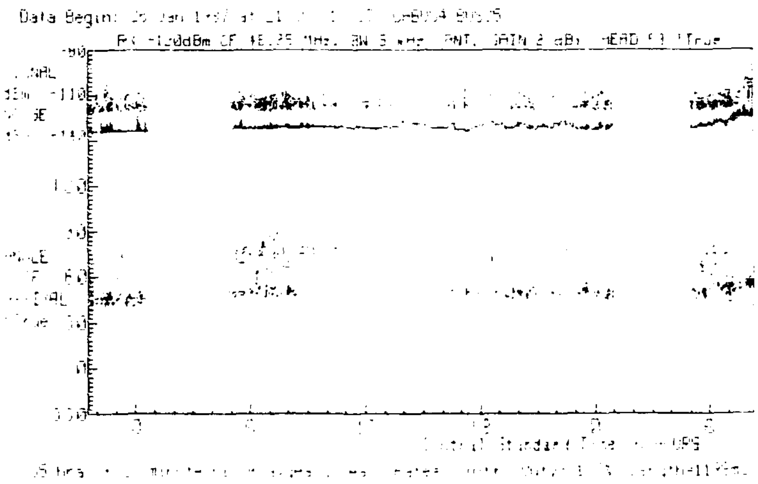


Figure 1 Signal reception from Brisbane TVQ channel 0 - summer 1987

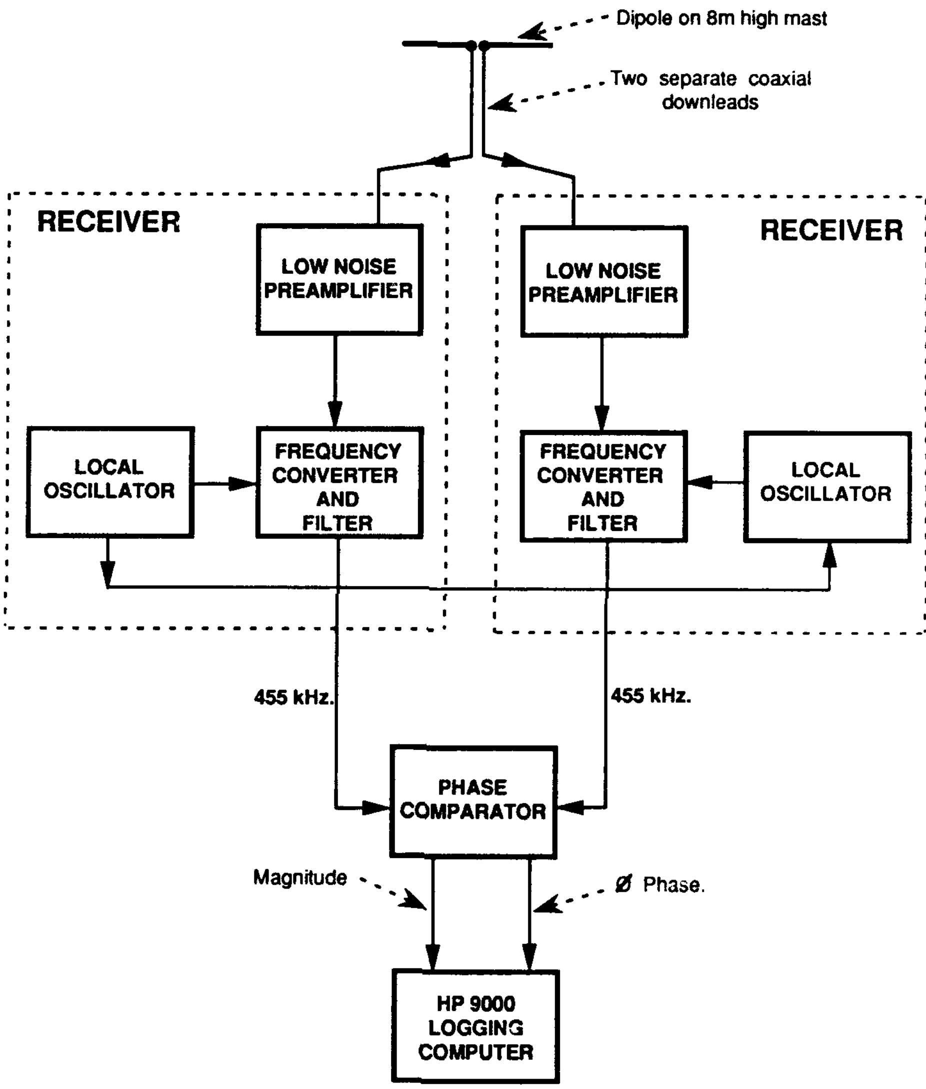


Figure 2 Block diagram of the Salisbury MBC receiving equipment

The TV station TVQ0 was logged again during the period from September 4th to 8th, when the station remained on air for 24 hours. Figure 3 below shows the angle of arrival pattern. The average burst rate during this period measured 74 per hour while the duty cycle was 0.7% (using the dipole antenna). The mean burst length (time above threshold) was 320 ms. Refer to Figure 4 below.

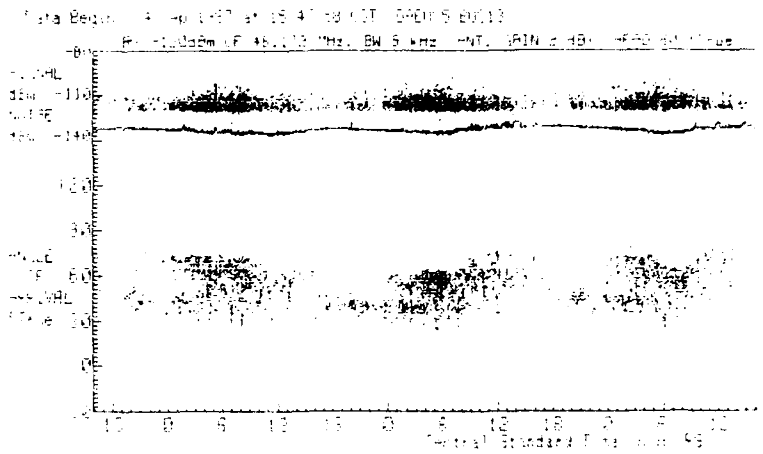


Figure 3 **Angle of arrival pattern - Brisbane TVQ channel 0, September 1987**

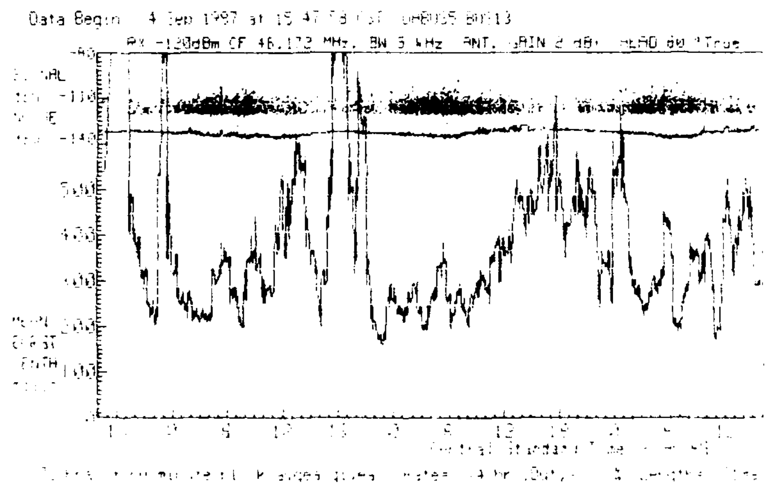


Figure 4 **Mean burst length - Brisbane TVQ channel 0, September 1987**

3 THE EXPERIMENTAL MBC SYSTEM

With the provision of two 500 W RF power amplifiers in September 1987 two experimental MBC systems were fabricated. One was used as the ERL base-station the other as the remote installation. With the exception of the power amplifiers, which were made by AWA, and the base-station logging computer which was a commercial item, all other components of the system were designed and manufactured at ERL. A block diagram of the system is shown in Figure 7. With the exception of the logging system, which was installed at the Salisbury Base-station only, the base-station and remote installations used similar equipment.

As shown in Figure 7 each installation comprised a transmitter, a double-conversion receiver and a microprocessor-based modem. A brief functional description of the equipment follows.

The transmitter signal was generated by a quartz crystal oscillator and varactor-tuned phase modulator at 44 MHz.

Serial data from the modem was encoded such that a binary 1 resulted in a 180° phase change while a binary 0 caused no change. The low level phase modulated signal was amplified by the exciter and power amplifier stages to a 500 W output. The receiver was fixed-tuned with a low noise (NF=3dB) RF input amplifier and double balanced mixer. The first IF stage (at 10.7 MHz) incorporated an impulse noise limiting amplifier (bandwidth≈180 kHz). The second IF stage (at 455 kHz) had automatic gain control and any one of four bandwidths selectable by the modem to suit the data bit rate (a bandwidth of approximately twice the bit rate is required). The phase modulation was detected by a dual bandwidth phase locked loop. Another phase locked loop was used to recover the clock frequency and decode the phase changes into serial data by means of low-pass filtering and mid-bit sampling [3].

The modem comprised an Intel 8085 processor system having EPROM/RAM and both parallel and serial interfacing. The protocol was designed for full duplex operation, although the remote terminal was programmed as a slave repeater, ie. all data received was transmitted back to the master station. This arrangement allowed the measurement of data throughput rates to be made at the master station, while the remote station was left unattended. The probe sequence of 56 bits is shown in Figure 8. The data transmission was divided into packets 152 bits long and transmitted at one of four fixed rates, viz. 1.2, 2.4, 4.8, or 9.6 kbits/s. Each packet carried 70 bits of data, arranged as ten ASCII characters. The remaining 82 bits were used for checksum, packet number, acknowledgement and synchronisation bits. Special command bits could also be sent to the remote modem to alter the transmission bit rate and other parameters.

Reception of the video carrier from station ABMN0 by meteor burst was recorded on February 11th and 12th 1987. The results are shown in Figure 5 below. At this range, (845 km), the burst rate is much higher, 122 bursts per hour, and the angles of arrival cover the full 180° of the measuring system. There is a slight indication of two hotspots about 40° apart with the southern side diminishing during the late afternoons. On July 10th 1987 the dipole antenna was replaced by a four-element horizontal yagi with a gain of 8 dBi. This antenna was installed on a 22 metre tower and pointed directly towards station ABMN (93° true). The numbers and length of bursts were logged over a 24 hour period. The results are shown in Figure 6. The plot of the burst rate, averaged over 20 minute intervals, shows a diurnal variation of between 100 and 900 bursts per hour, (average 500 bursts per hour). The mean length of a burst was 300 ms.

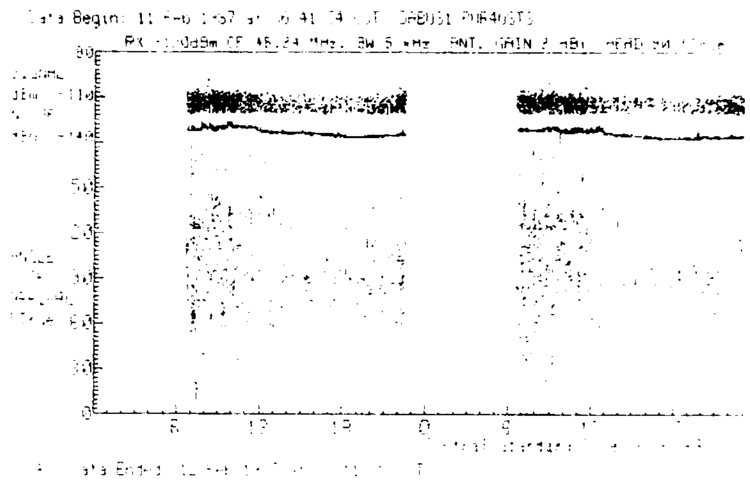


Figure 5 Angle of arrival pattern - ABMN, TV channel 0, February 1987

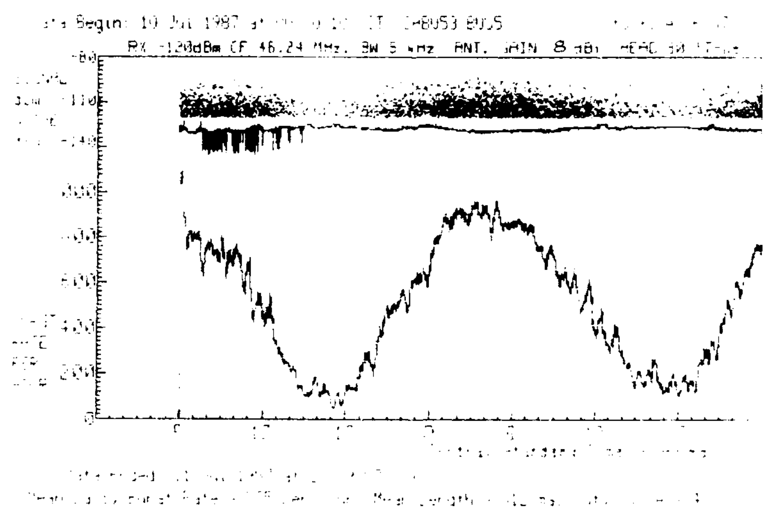
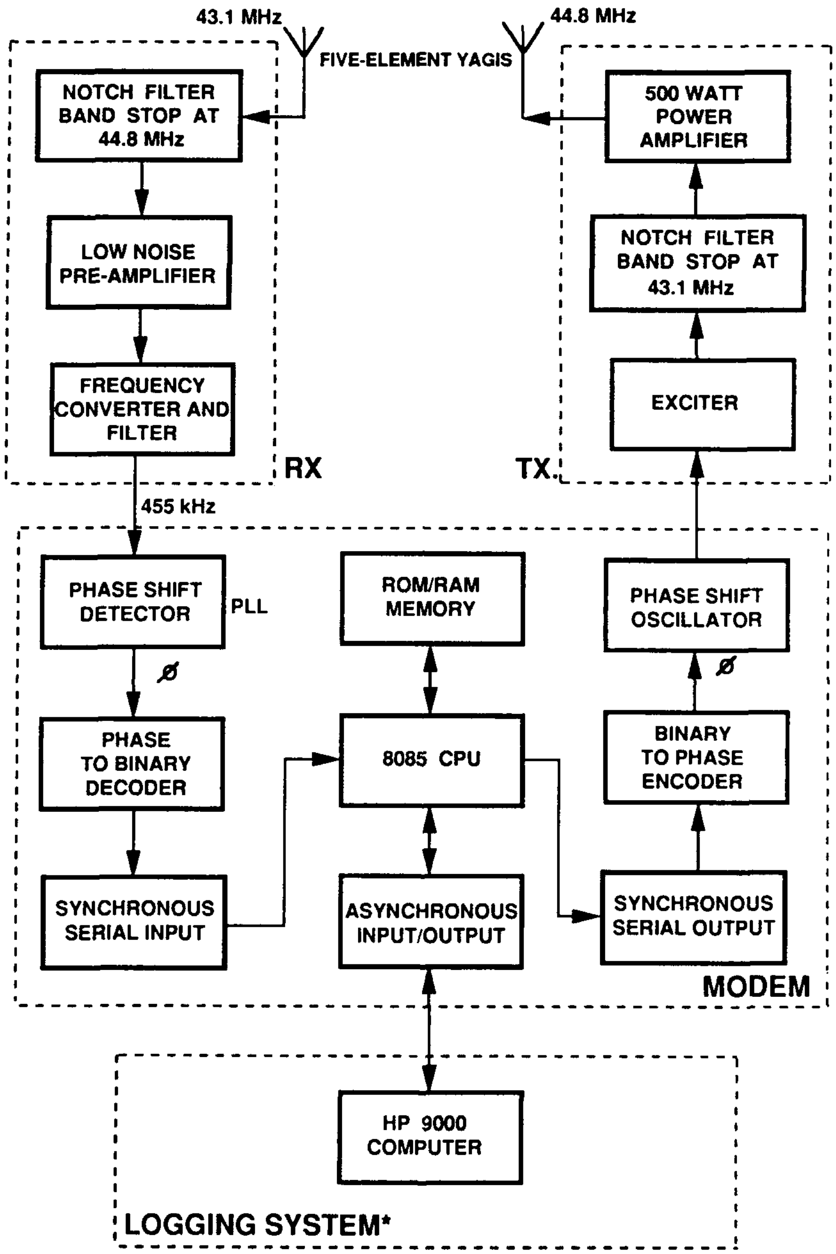


Figure 6 Mean burst rate - ABMN, TV channel 0, July 1987



* At Salisbury site only.

Figure 7 The experimental MBC system

The original protocol design required each packet to be transmitted repeatedly until acknowledgement was detected in the incoming data packets. This approach proved to be inefficient because nearly every packet had to be sent twice before acknowledgement was received. In January 1989 a modified protocol was devised whereby the transmitted and received packets were synchronised. This minimised the delay in detecting acknowledgements and increased the actual data throughput by some 60 percent.

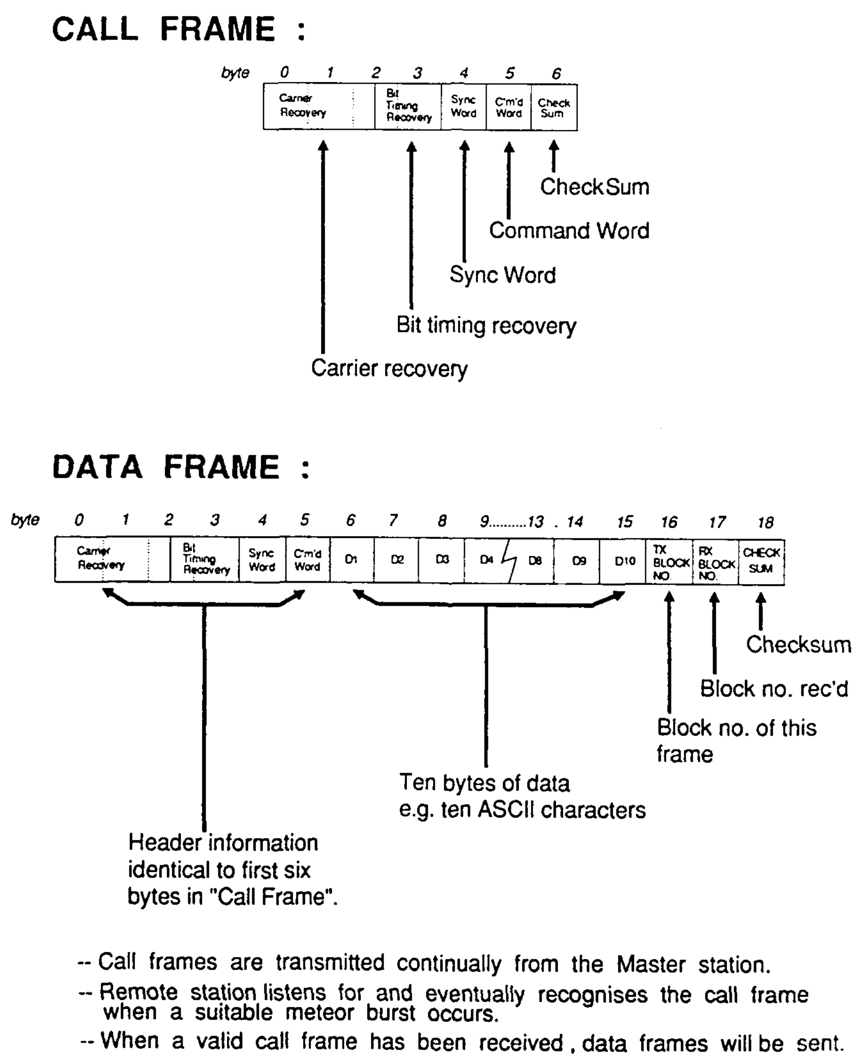


Figure 8 Meteor burst communications packeting format

4 MBC TESTS SALISBURY - WOOMERA

The experimental MBC system was set up during November 1987 between Salisbury and Range G at Woomera, a distance of 440 km. Two frequencies were used 43.1 MHz and 43.8 MHz*. Both stations transmitted continuously in full duplex mode.

**This was later changed to 44.8 MHz.*

The antennas used at both sites were four-element yagis mounted on fourteen metre high masts and coupled to the associated receiver and transmitter through diplexer-filters having six coaxial resonators. Because the maximum power rating of the filters is 300 W, the full transmitter output power could not be utilised. The estimated radiated power from each site was 1 kW IERP.

The initial results were disappointing as only a very small amount of data was transmitted over the link, about one character per minute on the average. The main reason for this poor result was high level RF noise in the receiver at the Salisbury site. The impulse noise limiter in the receiver was unable to cope with the problem. The noise was subsequently traced to a 33 kV power line passing some 300 metres in front of the antenna. In addition, the weather prevailing at the time was hot and dry, a condition known to exacerbate power line noise. Although wire brushes later fitted into the insulator couplings of the power line lowered the noise level considerably, the problem did not entirely abate until the onset of cooler weather.

Another source of interference to reception at both the Salisbury and Woomera sites was traced to loose and vibrating antenna and mast components. As this problem is inherent when using the one antenna for both transmitting and receiving it was subsequently decided to use separate antennas for reception and transmission at both sites. This had the added advantage that the diplexer filter was then not needed so the full output power of the transmitter (2.3kW IERP) could be used. The transmit yagis at both sites were mounted on fourteen metre high masts and had a vertical tilt of 20°. The receiving yagi at the Salisbury site was mounted on a 22 metre tower positioned thirty metres away from the transmitter mast.

With this antenna configuration, the data throughput of the system increased eightfold. The daily average data rate increased to approximately ten characters per minute.

A further cause of spurious noise in the receiver was traced to radiation from the digital circuits in the modem which, being constructed as an open card frame, picked up the strong field from the transmitter and re-radiated spurious intermodulation products. Some careful attention to shielding and filtering of cables into the modem subsequently reduced this problem.

Another serious but less frequent phenomenon observed during stormy weather was rain static. This was heard as a rasping noise and is thought to be caused by the discharge of static electricity from sharp points on the antenna. It usually lasted for only a few minutes but while present, very few meteor bursts were strong enough to overcome it.

Motivated by the need to minimise the persistant interference from power line noise, the Salisbury receiving antenna was replaced by a five-element yagi mounted on a four metre high mast and tilted upward at 30^{o} degrees. As expected, the noise pickup from this yagi, with its high angle of radiation, was about 6dB lower. As a result the data throughput increased to about 13 characters per minute. Encouraged by this improvement, the Salisbury receiving and transmitting yagis were further tilted to 45^{o} and moved lower down on their masts so that the reflectors were then only one metre above ground. This made a startling improvement to the data throughput, doubling it to 27 characters per minute. Figure 9 below shows the average performance of the system for each receiving antenna elevation angle.

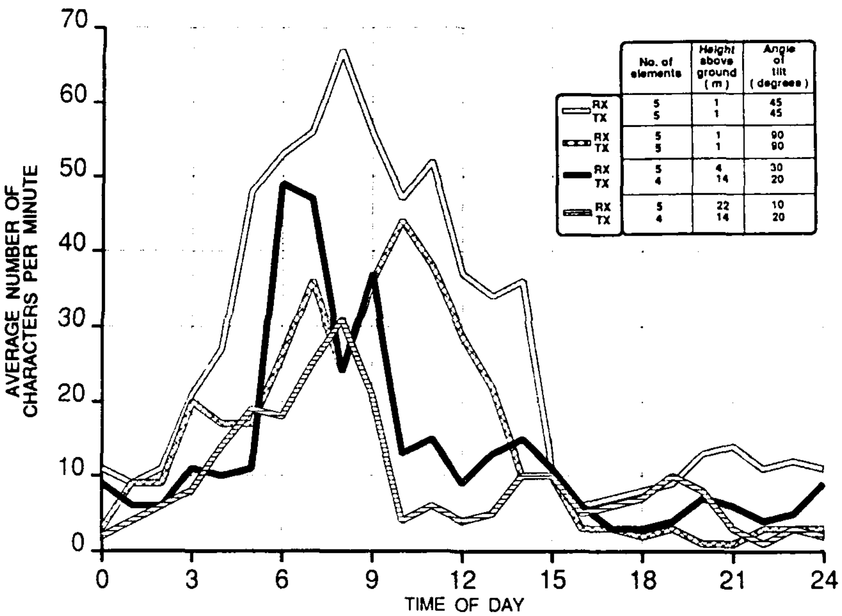


Figure 9 **Average daily throughput using different antenna heights and angles of tilt**

Finally both the Salisbury transmit and receive yagis were tilted to 90^{o} to utilise meteor trails in the region directly above Salisbury. Only one data rate (9.6 kbits/s) was tried and this gave an average throughput of 18 characters per minute. While this was lower than was achieved with the yagis at a tilt angle of 45^{o}, it was still better than with the antennas mounted high on the tower. With the yagis returned to a tilt angle of 45^{o}, throughput measurements were then performed at transmission bit rates of 1.2, 2.4, 4.8 and 9.6 kbits/s. The results are shown in Figure 10.

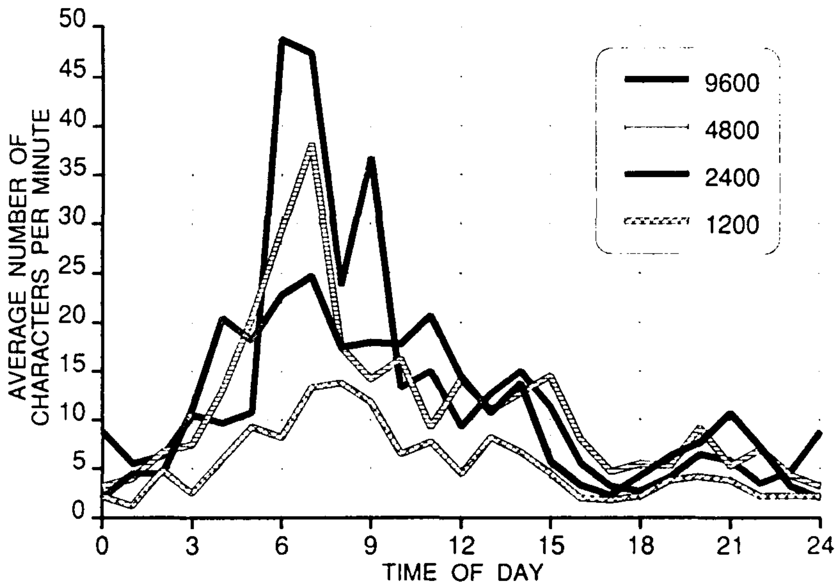


Figure 10 Average daily throughput for various bit rates (antenna tilt angle 45°)

The dual receiver system with the special dipole antenna, which was used initially to monitor the channel 0 TV transmissions (see paragraph 2), was used again to examine the spread of the angles of arrival of meteor bursts from Woomera. As expected, because of the shorter path they showed a very wide dispersion. The results are shown in Figure 11 below while the burst rate is shown in Figure 12. Figure 13 shows the increase in burst rate when using the yagi antenna instead of the dipole. It also illustrates the effect of high power line noise, eg. between 4 am and 6 am on the second day. The average burst length over this path was 250 ms.

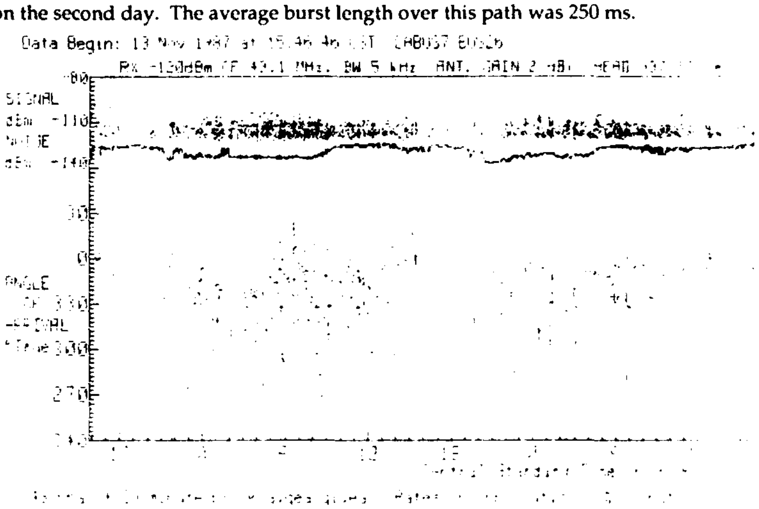


Figure 11 Angle of arrival pattern using dipole antenna - Woomera transmissions - November 1987

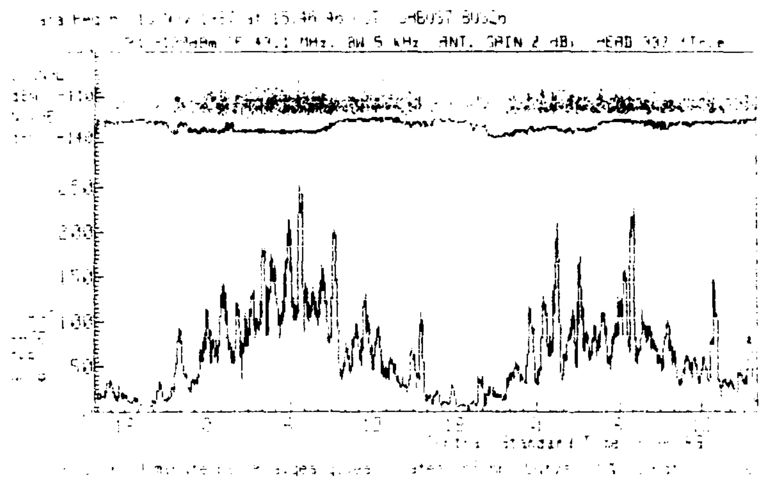


Figure 12 Mean burst rate using dipole antenna - Woomera transmissions - November 1987

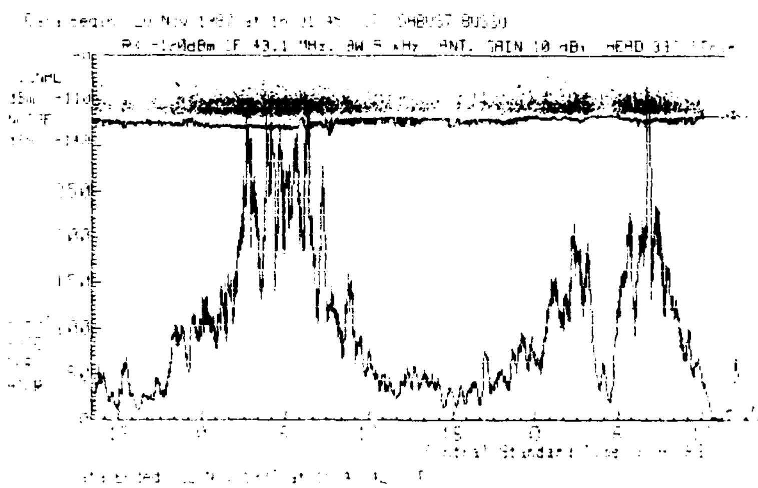


Figure 13 Mean burst rate using yagi antenna - Woomera transmissions - November 1987

5 MBC TESTS SALISBURY - JERVIS BAY

In September 1988 the remote site equipment was re-located to Jervis Bay on the east coast of Australia. It was positioned adjacent to the Jindivik airfield (latitude 35° South, longitude 151° East). The site had an inherently low RF noise level and was ideally situated 1100 km east of Salisbury.

Two similar antennas were used for the transmitter and the receiver. Each consisted of a five-element yagi mounted on a fourteen metre mast. Both yagis were tilted to 10° and aimed towards Salisbury. The Salisbury transmit yagi was (as for the Woomera trial) mounted at a height of fourteen metres and a tilt angle of 20°. The Salisbury receiving yagi was mounted initially on the 22 metre tower. Both antennae were directed at Jervis Bay.

As expected, the data throughput over this mid-range distance was much greater than had been experienced on the shorter Salisbury-Woomera link. After resolving some minor initial problems, the average daily throughput over the period from September 22 to December 9, was *typically 160 characters per minute, which was equivalent to a mean speed of 20 bits/s.* In January 1989 a new protocol was introduced (see also page 8) and this made a 60 percent improvement. This improvement factor when applied to the earlier results would have lifted the throughput to 256 characters per minute or 32 bits/s. Figure 14 shows the mean hourly data throughput, adjusted by the protocol improvement factor, using a transmission rate of 2.4 kbits/s.

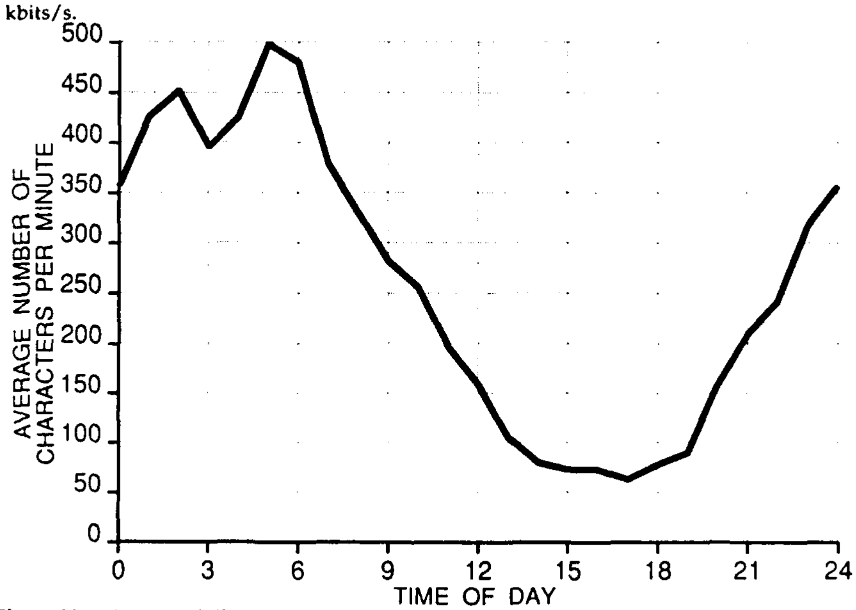


Figure 14 Average daily throughput - Salisbury/Jervis Bay using a 2.4 kbits/s data rate (September to December 1988)

Note: *During November, meteor activity increased, probably due to the Leonids stream. A typical daily throughput rate during this period (adjusted by the improvement factor) was 480 characters per minute, or 60 bits/s.*

With the onset of the warmer summer months, sporadic-E activity began to influence the performance of the system. For example, in November 1988 there were four days when sporadic-E openings were observed lasting between one and five hours; in December there were six such days, while during January 1989 there were fourteen days on which sporadic-E propagation lasted for over an hour. Only three days in January passed without any sporadic-E activity. Figure 15 shows the mean hourly throughput rates over the January-February midsummer period, compared with the 'quieter' period of March-April.

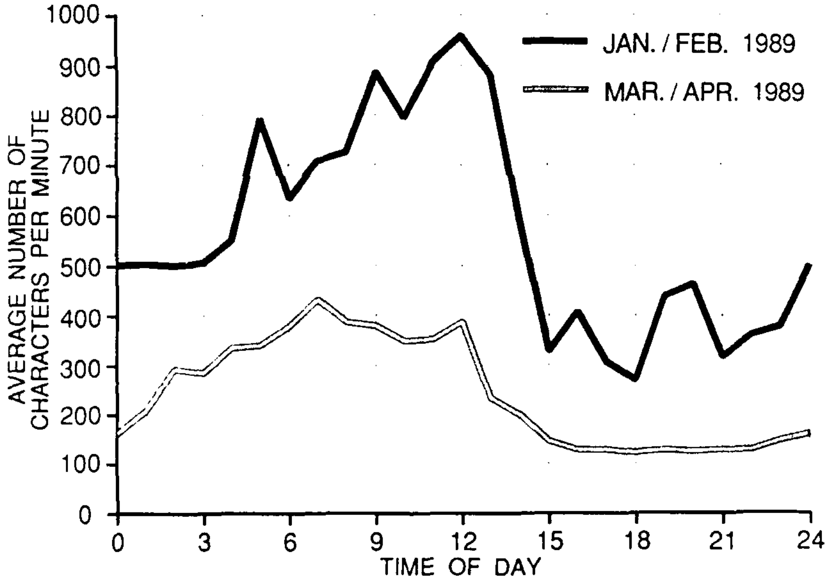


Figure 15 Average daily throughput - Salisbury/Jervis Bay using 2.4 kbits/s data rate - January/February and March/April

Increased meteor shower activity, probably associated with the Perseids stream, caused an increase in data throughput during the months of July and August. This is shown compared with the March-April period, in Figure 16.

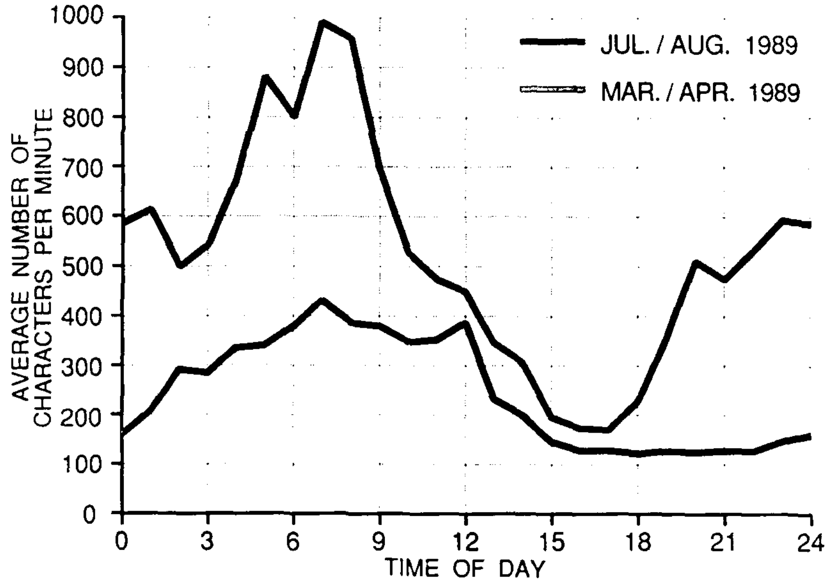


Figure 16 Average daily throughput - Salisbury/Jervis Bay using 2.4 kbits/s data rate. July/August and March/April

To further test the effect of receiving antenna height and to raise the radiation angle (and therefore reduce the effect of power line noise) a second yagi antenna was provided. This was mounted on a nine metre high mast. Both it and the 22 metre high yagi were then connected to the receiver via a time switch which automatically changed the antennae over each half hour. This arrangement enabled the effect of receiving antenna height on the total throughput of the system to be readily assessed. The results showed the lower antenna height to provide a 60 to 100 percent improvement in throughput. Note that the transmitting antenna was fixed at a height of fourteen metres. The results of this test are shown in Figure 17 overleaf.

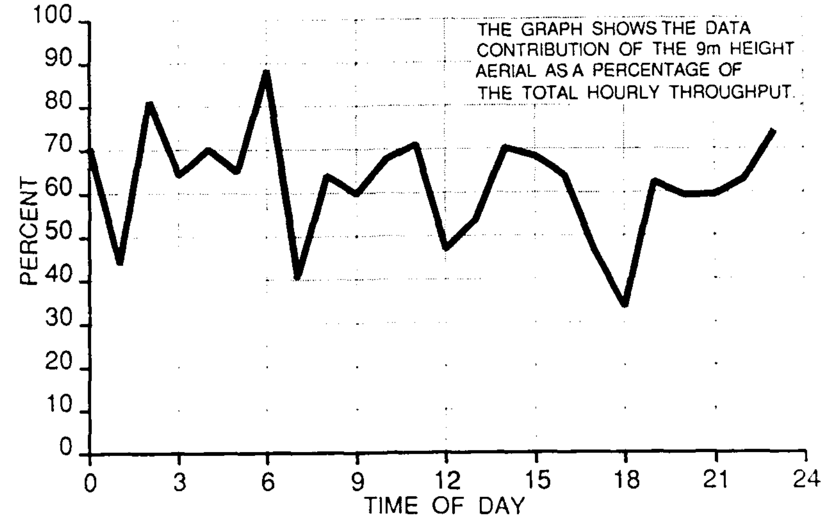


Figure 17 Comparison of total throughput using receiving antennas of different heights

The dual receiver system and the special dipole antenna initially used to monitor the channel 0 TV transmissions were again used to examine the angles of arrival of meteor bursts from Jervis Bay. The distribution as plotted in Figure 18 reveals two hotspots at plus and minus 11^{o} from the centre, 96^{o} true. The average burst length for this path was one second. The computer plotting program was made to separate the rate of bursts arriving from the two hotspots. These are shown in Figures 19 and 20. As shown in Figure 20, the southern hotspot is prominent in the morning but v nishes in the evening. Figure 19 shows that the northern hotspot is weaker but has less diurnal variation.

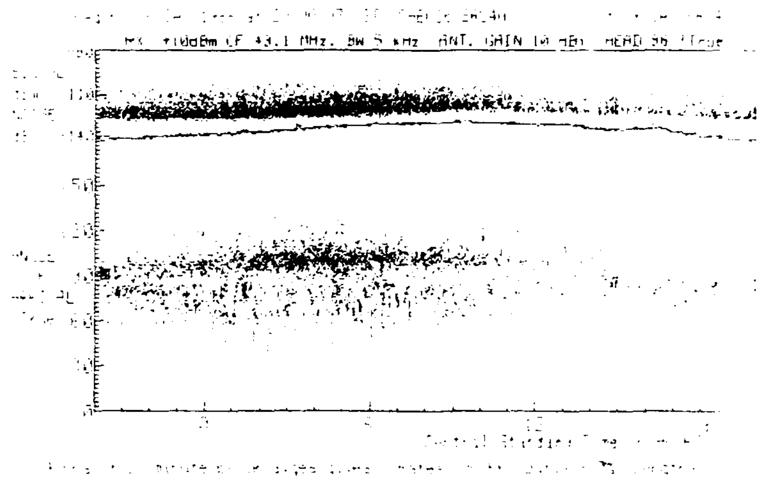


Figure 18 Angle of arrival pattern using dipole antenna - Jervis Bay transmissions

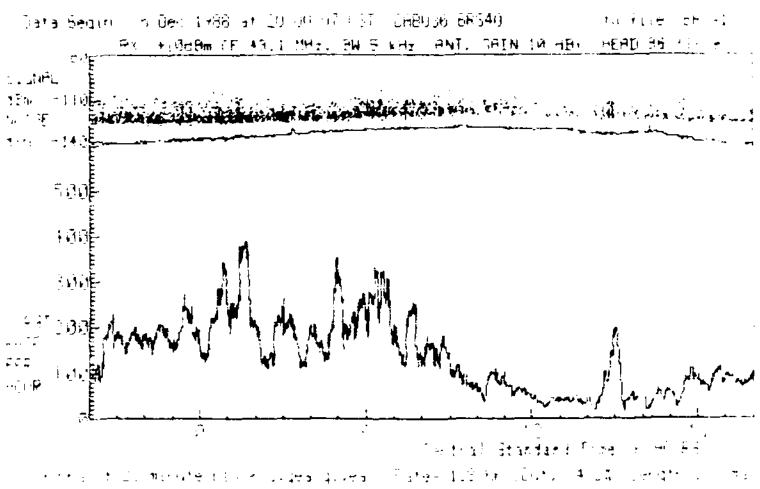


Figure 19 Meteor burst rate from the northern hotspot

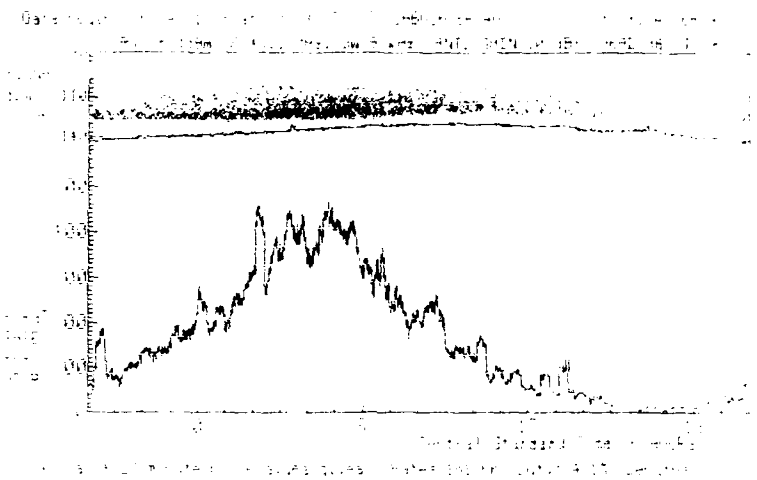


Figure 20 Meteor burst rate from the southern hotspot

A method was devised to improve the system data throughput by attempting to follow these hotspots using a steerable phased yagi array. This array consisted of two five-element yagis mounted on eight metre masts separated laterally by a distance of eight metres (1.2 wavelengths). The two feeders were combined through a switch to facilitate the phasing (and therefore the pointing angle) of the beam. The results were logged on the halfhour, alternately pointing at each hotspot and using a single five-element yagi for comparison. This experiment proved to be inconclusive, however, probably because the beamwidth of the phased array was too wide (40^{o}) to isolate the hotspots.

It is worthy of note that the year 1989 is a high point in the solar cycle. In March there were some unusually large solar flares and an Aurora Australis was visible from Australia and New Zealand. These events were accompanied by a high radio noise level and unusual ionospheric activity. Also, during April 1989 a problem was encountered with interference from overseas radio services propagated (presumably) by transequatorial ionospheric F mode. Stations in the USA, Asia and Indonesia were heard in the 39 to 45 MHz band. This phenomenon could be a serious problem if using MBC at locations in the tropical latitudes.

An additional experiment was performed using very low transmitter power. The power amplifier was bypassed and the 10 W exciter connected directly to the antenna at both Jervis Bay and Salisbury. As was expected, most communication was obtained from the longer, normally stronger, signals arising from overdense meteor trails. The daily throughput when using a power of only 10 W was approximately five percent of that normally obtained using the 500 W tranmitter power. In addition waiting times were very long.

6 EXPERIMENTS AT HIGHER FREQUENCIES

Following the conclusion of the Salisbury-Woomera and Salisbury-Jervis Bay trials, an attempt was made to monitor the meteor burst reception of FM transmissions from distant locations in the 88 to 108 MHz band. The antenna used for this exercise was a ten-element yagi having a six metre boom mounted eight metres above the ground. The receiver used for the experiment was based on one of the 44 MHz units but included the addition of a low noise RF FM preamplifier and a double balanced mixer. A synthesiser signal generator was used as the local oscillator to facilitate selection of the FM transmissions. The IF bandwidth of the receiver was 40 kHz.

Station 2MMM-FM in Sydney, 1160 kms from Salisbury and broadcasting on 104.9 MHz with a power of 35 kW was chosen as the target transmission because there was no other station of comparable transmission power sharing the same frequency. The daily average burst rate was found to be 90 per hour while the mean length of a burst was 140 ms. This gave an equivalent duty cycle of 0.35%. The hourly burst rate, taken over 20 minute averaging periods, was rather more erratic than the smooth sinusoidal shape observed for signals in the 44 MHz band. This is shown in Figure 21 below.

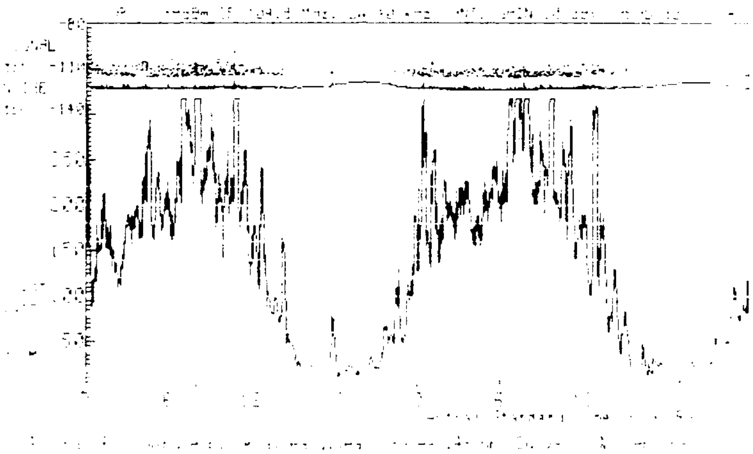


Figure 21 Meteor burst rate from Sydney FM station

On 13th March 1989, while monitoring 2MMM with the ten-element yagi directed due east, extremely high levels of solar noise were heard while the sun was in the beam at daybreak. This noise rose to 9dB above the galactic noise level. The IPS Radio and Space Service reported a very high incidence of solar flare activity at the time. The next day (March 14th) a number of weak FM stations were heard, all with badly distorted sound. Whilst identification was generally difficult, one station was identified on 103.2 MHz as 2CBA-FM in Sydney. On that day an Aurora Australis was seen from various parts of the country.

7 CONCLUSIONS

The study has provided valuable practical experience in the operation and design of an MBC system and in the understanding of the unique properties of the meteor burst channel. Long-term seasonal variations were difficult to discern because of the wide variations in performance caused by other parameters, in particular, changes to the antenna configuration. Temporary performance variations were also caused in the summer months by higher power line noise and sporadic-E propagation and during the months of May, June, July, November and December by meteor streams.

When establishing an MBC system the following particular points need to be considered.

1. The system needs to be sited well clear of suspended high tension power lines as noise from these can seriously degrade the performance of the system. This problem is most acute in hot dry weather.

2. When operating a full duplex system, the method of using the one antenna for both transmission and reception requires care to ensure that no looseness develops in the joints of the antenna or in the mast structure itself as this will cause noise in the receiver.

3. Some electronic computing equipment, eg. VDUs and printers, generate high levels of EMI and this can adversely affect a sensitive MBC receiver.

4. In a full duplex system the frequency separation between the transmitter and the receiver should be carefully chosen to avoid the risk of intermodulation occurring with nearby high power medium wave transmitters, particularly AM broadcast stations in the range 200 to 1600 kHz.

5. Antennas should be mounted at optimum height according to the range between stations. For ranges under 1000 km there is no advantage in having a mast height greater than ten metres. For ranges under 500 km, and particularly where one station is located in a noisy environment, improved performance may be achieved by tilting the antennas at the noisy station to a high angle to reduce the noise pickup. Antennas at the other station should be correspondingly lowered to aim towards the common volume of the meteor trail region closer to the noisy location.

With regard to transmission bit rate, the conclusions drawn from the study are that over the 440 km link to Woomera, the highest data throughput was obtained with the fastest bit rate, ie. 9.6 kbits/s. A bit rate of 4.8 kbits/s also achieved a high data rate and might be better for very brief messages. This result was consistent with the short average length (300 ms) of bursts over this path. The data throughput using a bit rate of 2.4 kbits/s was only two thirds of that of the higher speeds while at 1.2 kbits/s the throughput dropped to a third.

It may be that over such a short path, data rates greater than 9.6 kbits/s would have given an even better throughput. Due to speed limitations with the 8085 processor used in the modem it was not possible to use bit rates in excess of 9.6 kbits/s.

Over the longer 1100 km path between Jervis Bay and Salisbury the difference between throughput using the four transmission speeds was not as marked. The three higher bit rates, viz 9.6, 4.8 and 2.4 kbits/s, gave similar results while the lowest bit rate used (1.2 kbits/s) resulted in a 40% reduction in throughput. It is also worthy of note that when operating with very low transmitter power (in the order of 10 W) on the 1100 km path, the lower transmission speeds achieved the best results, although the difference between daily throughput was not significant. The throughput is, however, more regular at the lower speeds. Whereas, at 9.6 kbits/s the waiting time exceeded an hour at times.

The basic antenna used for the study was a Yagi-Uda parasitic array constructed from aluminium tubing with five 25 mm. diameter elements clamped to a 50 mm. diameter six metre long boom. The estimated gain was 9 dBi and horizontal polarisation was used. Some experimenting was performed, at the Salisbury site using different antenna vertical tilting angles and heights. In general, the best result was obtained when the antenna was mounted at the optimum height, ie. where the first major lobe of the vertical radiation pattern was aimed directly at the region of maximum meteor trail activity. An antenna which is mounted too high may result in more noise pickup from man-made sources. On the short path to Woomera (440 km) surprisingly good performance was obtained when both transmit and receive yagis at Salisbury were directed vertically. This may be an advantage for portable or mobile stations since there would be no need for a mast.

MBC technology is best suited to fixed or transportable stations requiring slow to medium data rates or telegraph communication over distances from 400 to 1600 km. At ranges up to 900 km the antenna requires only a small mast thus making it well suited to portable operation. Although there are daily fluctuations in meteor activity, MBC is more dependable than HF ionospheric communications. Because there is no need for frequency changes, MBC equipment can be used for unattended remote stations, such as environmental monitoring or remote surveillance. Further to this, where the data throughput requirements are low the average transmission time will also be low so that the use of solar panel/battery power is practical.

For applications requiring greater data throughput and shorter waiting time, the transmitter power may be increased towards the practical limit. For example, The Alaskan Air Command MBC System uses 10 kW transmitters feeding high gain antennas to deliver their long range surveillance radar data to the command center.

An improvement in the overall performance of an MBC system could be obtained from a dynamically adaptive bit rate system because of the widely varying characteristics of the meteor burst channel. Bursts vary widely in intensity and length on any particular path. The practical effectiveness of using such an adaptive modem would depend on its ability to rapidly decide the receiver channel quality and send its decision to the transmitter at the other end. It

was not possible during this study to attempt the design of such a modem. There has, however, already been some development on an adaptive bit rate modem by a commercial company in the USA. The company reports increased performance and a doubling of the throughput.

8 SUGGESTIONS FOR FURTHER WORK.

This initial MBC study has provided valuable experience in the practicalities of building and operating MBC equipment. A considerable number of publications exist which measure or estimate the performance of MBC systems in the Northern Hemisphere. A helpful reference subset is listed in Reference 1. The results of the study conducted by ERL are consistent with those found in these publications. They illustrate such features as diurnal and seasonal variation and angle of arrival hotspots.

One aspect which needs to be addressed is the determination of a quantitative computer model that can provide an estimation of the expected data throughput and waiting time for any particular MBC circuit and equipment configuration.

The US Defence Communications Agency Meteor Burst software program (BLINK) has been recently acquired by ERL. This program predicts a throughput for the Salisbury/Jervis Bay link of around one tenth of that actually measured. It is therefore suggested that a model calibrated for the southern hemisphere be made to predict MBC system performance, given the equipment and location parameters.

Issues of adaptive bit rate, forward error correction and cryptographic compatibility were not addressed during the ERL study. It is suggested that these topics be addressed as part of the emerging work on modulation and coding.

It was not possible during this study to try an airborne MBC system. MBC systems have however, already been operated from aircraft in the USA and the UK.

Considering the current development being undertaken overseas by the commercial sector, particularly in the USA, the value of conducting research and development in MBC systems per se is doubtful. Of more value to Australia would be the study of specific MBC algorithms in an uncommitted radio test bed [4] to validate the model and to obtain a measure of MBC performance against the usual LOS and BLOS propagation modes.

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THIS REPORT DOCUMENTS THE RESULTS OF A STUDY INTO THE USE OF A METEOR BURST COMMUNICATION SYSTEM OVER THE SOUTHERN PART OF THE AUSTRALIA N CONTINENT. ALSO INCLUDED IS A DESCRIPTION OF THE EQUIPMENT USED IN THE STUDY AND SOME SUGGESTIONS FOR FURTHER WORK.

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